6.1 Introduction
Thin film technologies are expected to substantially reduce manufacturing costs of solar cells due to the lowering of material expenses and the deposition on large area substrates of a nodule size. Achievements in material science and in device development of semiconductors have led to impressively high efficiencies in the laboratory and in some cases to pilot production and manufacturing plants. CIS photoabsorbers (CuInSe2 and related quaternary compounds containing Ga called CIGS) are among the most promising photovoltaic materials. Chalcopyrite films in a polycrystalline form have resulted in solar cells with laboratory efficiencies exceeding 18 % [1-3]. CIS solar cells show very good outdoor stability and radiation resistance [4-5]. The mixed or alloyed semiconductors belonging to I-III-VI group of the periodic table, particularly chalcogenides are important due to their wide spectrum utility in various opto-electronic devices such as IR detector, photoconductive, photovoltaic cells, light amplification, LEDs, lasers, electro photography and PEC cells [6-10]. In the preceding chapters, the technical know-how methodology, essential requirements for construction, fabrication and use of Li doped CuInSe2 thin films in PEC cells have been studied in detail. From these studies, it has been realized that a considerable improvement in the photoelectrochemical performance of cell has been obtained with CuInSe2 thin films. However, the observed performance of the PEC cell was found to be much smaller than the existing literature reported value. There are several reasons in general; one of the reasons is higher resistivity of the photo electrode material. An effective way to reduce the resistivity and to improve the properties of photo electrode material is to dope with a suitable impurity (donor) like Lithium, silver, aluminum, and antimony. The doping has shown to enhance properties in number of host lattices [11-15]. The low resistivity and higher grain size of the photoelectrode material are the parameters which influence the open circuit voltage and short circuit current of the cell. In this chapter therefore, the attempts are made to study
the effect of lithium doping on the electrical, optical, thermo-electrical, structural morphological and photo-electrochemical properties of optimum composition CuInSe$_2$ thin films described in section 4.3.

6.2 Experimental Details

6.2.1 Preparation of Lithium doped CuInSe$_2$ Thin Films

The deposition of Li doped CIS thin film was made in a reactive solution obtained by mixing 5 mL (0.02M) copper sulphate, 5 mL (0.02M) indium trichloride, 1mL (0.25M) tartaric acid, 10 mL (2%) hydrazine hydrate and 10 mL (0.025M) sodium selenosulphate. For a desired doping level, lithium chloride solution was directly added to bath. The total volume of the reactive mixture was made to 80 mL by adding double distilled water. The beaker containing the reactive solution was transferred to an ice bath at 273 K temperature. The pH of the resulting solution was found to be 10.±0.05. Four cleaned glass substrates were positioned vertically on a specially designed substrate holder and rotated in reactive solution with a speed of 50±2 rpm. The temperature of the solution was then allowed to rise slowly upto 305 K. The substrates were subsequently removed from the beaker after 4 hr of deposition. The films obtained were washed with distilled water, dried in air and kept in desiccator.

6.2.2 Characterization of Lithium doped CuInSe$_2$ Thin Films

The Li doped CIS films were characterized by using a Philips PW-1710 X-ray diffractometer in 2$\theta$ range from 20$^0$ to 80$^0$, using CrK$\alpha$1 line (wavelength 2.28970 Å). The electrical resistance measurements were carried out in temperature range 300 – 525 K using two probe method. Silver paste was used for ohmic contact purpose. Thermoelectric power measurements were done by maintaining a temperature gradient over the length of film. A thermocouple of chromel-alumel (24 gauges, calibrated) was used to sense working temperature. The spectrum of optical absorption was recorded in wavelength range 850-1200
nm by using a Hitachi 330 (Japan) double beam spectrometer at room temperature computing the value of absorption at every step of 5 nm. The film composition was determined using Perkin Elmer 3030 atomic absorption spectrophotometer. A study of surface morphology of thin film was done under scanning electron microscope (SEM), 250 MK – III, Cambridge UK. Surface roughness can be studied by atomic force microscopy (AFM) technique. For photo-electrochemical characterization, Li doped CuInSe$_2$ thin films deposited on stainless steel plates were used as photo anode, sulphide polysulphide as electrolyte and CoS treated graphite rod as counter electrode. I-V, C-V, characteristics in dark and power output curves under constant illumination of 30 mW/cm$^2$ were determined. To determined built-in- potential, reverse saturation current was measured in the temperature range 303-373K. Photo-response was also recorded. The performance parameters such as $n_d$, $\Phi b$, $I_{SC}$, $V_{OC}$, $\eta$%, ff%, $R_S$, $R_{Sh}$, etc were computed from the data obtained.

6.3 Results and Discussion.

6.3.1 Physical Properties

The Li doped CuInSe$_2$ thin films as deposited on a glass substrate were found to be uniform, well adherent to the substrate. The colour of the film was found to vary from light green to green with increase in lithium concentration. The thickness of the film was found to be maximum at 0.1 mol % of Li. Thickness of the film was measured as a function of deposition time in minutes which is shown in fig.6.1. The thickness was also measured as a function of temperature and the variation is shown in fig.6.2. The increase in film thickness is attributed to substitutional inclusion of lithium ions in the interstitial position of the lattice or in the cationic vacancies already present in the host. At higher doping concentration, the impurity atom may be occupying interstitial sites preventing further growth of the film [16, 17]. The doping concentration of lithium in the film was estimated by AAS method.
Fig 6.1 A plot of thickness versus time for Li doped CuInSe$_2$ thin film (0.1 mol % Lithium concentration)

Fig 6.2 A plot of thickness versus temperature for Li doped CuInSe$_2$ thin film (0.1 mol % Lithium concentration)
6.3.2 X-Ray Diffraction studies

The X-ray diffractogram of lithium doped CuInSe$_2$ films are shown in Figure. 6.3. The presence of a number of peaks indicates the crystalline nature of the film. The peak intensity and hence the crystallinity of the films were found to be enhanced with increase in lithium concentration from 0.01, 0.025, 0.075, 0.25, 0.1, mol %, for lithium concentration. This behavior is justified on the basis of surface adsorption of lithium atoms over a growing film preventing further growth of the microcrystals. The similar types of results have been obtained on doping of host structure with Na, Zn, and Ag, [18-20]. The prominent peaks shown by all samples correspond to reflection from 211 (2.532 Å), 213 (2.150 Å), and 312 (1.7109 Å) planes of a tetragonal lattice, for lithium doped films, the highest peak occurs at the same d value with a little modification of peak width and intensity, for all the films as evaluated using equation:

\[
\frac{1}{d^2} = \frac{h^2 + k^2}{a^2} + \frac{l^2}{c^2} \]

Where ‘d’ is the interplanar distance (Å), h, k, l, are planes and ‘a’ is the cell size (in Å). It is observed that the film with 0.1 mol %. Lithium doping concentration exhibits highest peak intensity. The grain size is seen to decrease from 363 Å to 344 Å as Li concentration increases from 0.0 to 0.075 % and then increases from 344 Å to 380 Å at 0.1 % Li. The analysis of XRD patterns in terms of hkl planes interplanar distances and particle size are included in Table.6.1.

6.3.3 Scanning Electron Microscopy (SEM)

The surface morphology of Li doped CuInSe$_2$ thin films were analyzed using scanning electron microscopy. Figure 6.4 displays the (SEM) image of Li doped CuInSe$_2$ samples with 0.01, 0.025, 0.075, 0.1 0.25 mol %. The grains are seen to be spherical where as the grain size and impactness are found to improve as lithium concentration in films is increased up to 0.1 mol %. The average grain sizes have been calculated using Contrellis’ relation [21] from SEM images. The spherical grain becomes scare at higher doping level losing compactness and the
film tends towards amorphous nature. The grain size calculated from SEM was found to tally with those obtained using XRD. The observed grain size is listed in Table 6.1.

![Graph 1](image1.png)

a) 0.01 % Li doped

![Graph 2](image2.png)

b) 0.025 % Li doped
c) 0.075 % Li doped

d) 0.1 % Li doped
Fig. 6.3 XRD pattern of Li doped CuInSe$_2$ thin films

- a) Li = 0.01 Mol %
- b) Li = 0.025 Mol %
- c) Li = 0.075 Mol %
- d) Li = 0.1 Mol %
- e) Li = 0.25 Mol %

e) 0.25 % Li doped
Chapter VI

a) 0.01 % Li

b) 0.025 % Li

c) 0.075 % Li
d) 0.1 % Li

e) 0.25% Li

Fig. 6.4 SEM micrographs of CuInSe₂: Li thin films

a) 0.01 mol% Li b) 0.025 mol% Li c) 0.075 mol% Li
d) 0.1 mol% Li e) 0.25 mol% Li
a) 0.01% Li
b) 0.025 % Li
c) 0.075 % Li
d) 0.1 % Li
e) 0.25 % Li

**Fig. 6.5** AFM micrographs of CuInSe$_2$: Li doped thin films

a) 0.01 mol% Li (3D,2D)  b) 0.025 mol% Li (3D,2D)  c) 0.075 mol% Li (3D,2D)  d) 0.1 mol% Li (3D,2D)  e) 0.25 mol% Li (3D,2D)
6.3.4 Atomic Force Microscopy

AFM has proved to be a unique method to analyze the surface morphology of the films. Figure 6.5 shows three dimensional (3D) and two dimensional (2D) images of Li doped CuInSe$_2$ thin films. It is seen that the film has spherical grains of different diameters with same surface roughness. This roughness of the films is unavoidable since particles are in spherical shapes, which shows semi-rounded hills on the upper surface. The agglomeration of particles in most of the cases is evident from the 2D micrographs.

The root mean square value of the surface roughness of the film (RgAFM) is calculated from a number of scans at different area of the film. It was observed that the surface roughness of the film is reasonably expected as the particles are probably made up of nano-structured grains as evidenced from X-ray and SEM observations.

6.3.5 Optical studies

The optical absorption spectra of lithium doped CuInSe$_2$ thin films deposited onto glass substrate were studied at room temperature in the wavelength of 850–1200 nm neglecting losses due to reflection and transmission. The absorption edge was found to shift from 1200 to 850 nm for lithium doping concentration up to 0.1 mol %. The energy band gaps were estimated from the variation of $(\alpha h\nu)^2$ versus $h\nu$ curves (Figure 6.6). The energy band gap increases from 0.81 to 1.1 eV as lithium concentration is increased up to 0.1 mol % while the value remains more or less constant for higher doping levels (Table 1). The observed variation in optical band gap, in our investigation may be attributed to Moss- Burstein shift, which occurs in doped semiconductor, due to the filling of states at the bottom of the band minimum as the doping level is increased. This filling of phase space leads to transition from the valence band to conduction band at higher energies and at k vectors away from the zone center increasing the onset of absorption energies [22].

\[ \alpha h\nu = A(h\nu - Eg)^n \]
where, the symbols have their usual meaning. Upto 0.1 mol % Li, the absorption edge shifted towards higher wavelength. This is due to filling of low lying energy level by conduction electron and segregation of the impurity along the grain boundary. A plot of \((ahv)^2\) Vs \(hν\) should be a straight line whose intercept to the x-axis gives the optical band gap. The plot of \((ahv)^2\) Vs \(hν\) for as deposited samples are shown in Figure 6.7. The linear nature of plot shows the existence of direct transition. However, the effect of dislocation and non-stoichiometry present in polycrystalline thin film cannot be ruled out and therefore it is reasonable to regard the above possibility.

6.3.6 Electrical properties

The electrical conductivity of as deposited Li doped CuInSe$_2$ films on the glass substrate was measured by using a dc two probe method in the temperature range 300–525 K. The specific conductance at room temperature of CuInSe$_2$ was found to be of the order of $10^{-2}$ (Ω cm)$^{-1}$. The electrical conductivity at room temperature increases with increase in lithium doping level up to 0.1 mol % and thereafter decreases for higher lithium concentration. Up to 0.1 mol % incorporation of Li in the lattice results in decrease in boundary potential and improvement in crystallite size, which results in increase of carrier concentration as well as mobility [23]. The activation energy is calculated using exponential form of Arrhenius equation;

$$\sigma = \sigma_0 \exp (-E_a/kT)$$

where, the terms have usual meaning. Therefore, it may be concluded that the increase in conductivity up to 0.1 mol % is largely controlled by the donating nature of the lithium for films with lithium concentration between 0.1 to 1 mol %. The observed decrease in conductivity can be due to interstitial occupation of lithium ions in the host, lattice acting predominantly as charge trapping centers. The variation of log $\sigma$ with 1000/ T for few lithium doped CuInSe$_2$ samples are shown in Figure 6.8. The activation energy of electrical conduction has been
determined from these plots and is included in Table 1. The temperature
dependence of the electrical conductivity shows a normal Arrhenius behavior in
high as well as low temperature range.

**Fig 6.6** Determination of band gap of Li doped CuInSe$_2$ thin film by various
doping concentration.

**Fig 6.7** Plot of $\ln (\alpha h \nu)$ versus $\ln (h \nu - E_g)$ for Li doped CuInSe$_2$ Photo-electrode.
6.3.7 Thermo Electric Power Measurement

In thermoelectric power measurements, the open circuit thermo voltage generated by the sample when a temperature gradient is applied across a length of the sample was measured using a digital micro voltmeter. The temperature difference between the two ends of the sample causes transport of carriers from the hot to cold end. The thermo voltage generated is directly proportional to temperature gradient maintained across the semiconductor ends. From sign of the potentiometer terminal connected at the cold end, one can deduced the sign of predominant charge carrier [24]. In the case of CuInSe₂: Li thin films, the negative terminal was connected to the cold end; therefore, the film shows n-type conductivity. The temperature dependence of thermoelectric power is shown in Figure 6.9. The thermoelectric power increases up to 0.1 mol % Li and there after decreases. The carrier density and mobility was determined for all the samples using equations mentioned in section 4.4.5. The plot of carrier density against temperature is shown in Figure 6.10. The carrier concentration decreases with doping.
concentration up to 0.1 mol % Li, thereafter for higher doping level it increases. However, mobility increases with doping concentration up to 0.1 mol % Li thereafter decreases. The height of the potential barrier at the grain boundary can be determined from the plot of log $\mu T^{1/2}$ versus 1000/T. Figure 6.11. shows such variation for some representative samples. The height of potential barrier at the grain boundary decreases with lithium concentration up to 0.1 mol %, but increases further for higher doping level.

6.3.8 Photo-electro Chemical Properties

i) I-V and C-V Characteristics in Dark

To know the nature of charge transfer across the photo electrode electrolyte interface, Butler-Volmer relation was used. The value of $\beta$ was greater than 0.5, confirming the rectifying nature of the interface. The current I developed is maximum for 0.1 mol% Li doping concentration. The junction ideality ($n_d$) was

![Graph](image_url)

**Fig 6.9** The temperature dependence of thermoelectric power for Li doped CuInSe$_2$ Photoelectrode.
Fig. 6.10. The temperature dependence of carrier density for Li doped CuInSe$_2$ Photoelectrode.

determined from the plot of log I versus V for all samples. Figure 6.12 shows variation of log I with V for samples. The junction ideality factor decreases from 3.37 to 2.47 as the doping concentration increases up to 0.1 mol% Li. For higher levels of doping concentration, the junction ideality factor increases. The lower value indicates the less trap density at the interface [25]. The flat band potential ($V_{fb}$) was found to increase from 812 to 823 mV, with doping concentration up to 0.1 mol% Li and thereafter decreases for higher doping level. This is because lithium creates new donor level, which shifts Fermi level in upward direction, thereby increasing the amount of band bending and hence flat band potential increases. At higher doping concentration, a pinning of Fermi level may decrease the flat band potential [26-27]. The plots deviate from linearity and indicate that the junction is graded type [28].
ii) Barrier Height Determination

The barrier height for Li doped in CuInSe$_2$ thin film were determined by measuring the reverse saturation current through the junction at various temperatures from 363 K to 303 K. From the plot of log $\mu T^2$ as a function of 1000/T (fig. 6.11) the barrier height was determined and from the plot of current log I against volt (V), (fig. 6.12) the junction ideality factor was determined. The non-linearity of plots in higher temperature region can be attributed to Pool-Frankel type of conduction mechanism. The barrier height was found to increase from 0.232 to 0.249 ($\Phi_e$ eV) as the doping concentration was increased up to 0.1 mol %. Li and then it decreases thereafter for higher doping concentration.

iii) Power Output Curves

The various power output characteristics of Li doped CuInSe$_2$ PEC cells were examined under 30 mW / cm$^2$ intensity. The power output curve for representative doping concentration is shown in Figure.6.14. It is seen that as the doping concentration increases up to 0.1 mol % Li, $V_{OC}$ as well as $I_{SC}$ are found to increase from 332 to 354 mV and 310 to 330 $\mu$A/cm$^2$ respectively. The increase in the $V_{OC}$ and $I_{SC}$ directly affects the conversion efficiency and fill factor. An improvement in conversion efficiency and fill factor has been noted for 0.1 mol % Li concentration.
Fig 6.11. A plot of $\log \mu T^{1/2}$ versus $1000/T$ for Li doped CuInSe$_2$ photoelectrode.

Fig. 6.12. Variation of $\log I$ Versus Volt (V) of Li doped CuInSe$_2$ photoelectrode.
Fig. 6.13. The C-V plots of Li doped doped CuInSe$_2$ photoelectrode

The increase in the $I_{SC}$ might be due to decreased photo electrode resistance and an increased absorbance by the material itself, while the enhancement in $V_{OC}$ could be correlated to the increase in flat band potential, barrier height and partly due to improved grain structure of the material itself [28-32]. The resistance of the cell was found to decrease up to 0.1mol % Li concentration and then to increase for higher doping level.

iv) Photo Response

The photo response of the cell was measured by noting the $I_{sc}$ and $V_{oc}$ as a function of light intensity $f_L$. The equivalent circuit diagram of the ECPV cell implies that $I_{sc}$ varies linearly with the light intensity as:

$$I_{sc} = C f_L$$

Where $C$ is a constant. Variation of short circuit current $I_{sc}$ and open circuit voltage $V_{oc}$ as a function of light intensity for the PEC cell are shown in Figure. 6.16 and 6.17. As expected variation of the short circuit current with the illumination intensity is linear whereas $V_{oc}$ varies initially linearly with the light intensity and then for higher levels of the illumination intensity shows saturation.
The lighted ideality factor ($\eta_L$) were determined for all the cells by plotting the log $I_{sc}$ Vs $V_{oc}$ (fig 6.18). The different performance parameters such as $n_d$, $\beta$, $I_{sc}$, $V_{oc}$, $\eta$ %, ff %, $R_s$, $R_{sh}$, $V_{fb}$, $\eta_L$ are included in the Table 6.3 for different lithium doped CuInSe$_2$ thin films.

![Diagram](image1.png)

**Fig.6.14.** Power output curves for Li doped CuInSe$_2$ photoelectrode

![Diagram](image2.png)

**Fig. 6.15.** Variation of log $I_0 / T^2$ for Li doped CuInSe$_2$ photoelectrode
Fig. 6.16. Variation of $V_{OC}$ with illumination intensity of Li doped CuInSe$_2$ photoelectrode

Fig. 6.17. Variation of $I_{SC}$ with illumination intensity of Li doped CuInSe$_2$ photoelectrode
Fig. 6.18. Plot of log Isc versus Voc for Li doped CuInSe$_2$ Photoelectrode.

6.4 Conclusion

Lithium doped CIS thin films have been prepared successfully by using simple chemical bath deposition technique. The films were found to be polycrystalline tetragonal phase without appreciable shifting in peak positions. The crystallinity and grain size were found to increase with lithium concentration up to 0.1 mol %, whereas for higher values, the material loses crystallinity. The lithium atoms were found to be dissolving substitutionally in the lattice of CuInSe$_2$ up to 0.1 mol % of lithium. The Absorption studies indicated presence of a direct band gap. The electrical conductivity studies indicated presence of two conduction mechanisms. The conductivity at room temperature was found to increase up to 0.1 mol % lithium. Both the carrier concentration and mobility were found to depend upon doping concentration and temperature. In PEC study the efficiency, Voc, Isc, and the fill factor have been found to enhance up to 0.1 mol % of lithium. An optimum doping level of 0.1 mol % gives a better performance. However, a special surface treatment is still necessary to enhance cell efficiency.
Table 6.1: Analysis of XRD pattern and other parameters of Li-doped CuInSe₂

<table>
<thead>
<tr>
<th>Dopant con. (Mol) %</th>
<th>Peak no</th>
<th>d’ values (ASTM) CuInSe₂: Li (Å)</th>
<th>d values Observed. (Å)</th>
<th>hkl Plane</th>
<th>Cell constant. a = b≠c (Å)</th>
<th>Grain size Å XRD (AFM)</th>
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<tbody>
<tr>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td>211 213</td>
<td>a = 5.741 b = 5.743 c = 11.51</td>
<td>363 (359)</td>
</tr>
<tr>
<td></td>
<td>1 2</td>
<td>2.500 1.999</td>
<td>2.532 1.999</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.025</td>
<td></td>
<td></td>
<td></td>
<td>211 213</td>
<td>a = 5.738 b = 5.737 c = 11.49</td>
<td>349 (343)</td>
</tr>
<tr>
<td></td>
<td>1 2</td>
<td>2.520 2.150</td>
<td>2.5725 2.160</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.075</td>
<td></td>
<td></td>
<td></td>
<td>211 213</td>
<td>a = 5.740 b = 5.735 c = 11.47</td>
<td>344 (339)</td>
</tr>
<tr>
<td></td>
<td>1 2</td>
<td>2.520 2.150</td>
<td>2.570 2.158</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td>211 213</td>
<td>a = 5.742 b= 5.740 c= 11.60</td>
<td>380 (374)</td>
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<td>2.634 2.151 1.710</td>
<td>211 213 312</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
<td>211 213</td>
<td>a = 5.746 b= 5.739 c= 11.54</td>
<td>373 (369)</td>
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<tr>
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<td>1 2</td>
<td>2.520 2.150</td>
<td>2.572 2.160</td>
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Table 6.2: Band gap and power factor of Li-doped CuInSe$_2$.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Mole % of Li in CuInSe$_2$</th>
<th>Band Gap (eV)</th>
<th>Power factor (m)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
<td>1.1</td>
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<tr>
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<td>0.81</td>
<td>0.482</td>
</tr>
<tr>
<td>3</td>
<td>0.05</td>
<td>0.92</td>
<td>0.512</td>
</tr>
<tr>
<td>4</td>
<td>0.1</td>
<td>1.12</td>
<td>0.478</td>
</tr>
<tr>
<td>5</td>
<td>0.5</td>
<td>1.19</td>
<td>0.496</td>
</tr>
<tr>
<td>6</td>
<td>1.0</td>
<td>1.30</td>
<td>0.507</td>
</tr>
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</table>

Table 6.3 Optical and electrical parameters of Lithium doped CuInSe$_2$ thin films.

<table>
<thead>
<tr>
<th>Sr.no</th>
<th>Mol % of Li doped in CuInSe$_2$</th>
<th>Band gap (eV)</th>
<th>Specific resistance ($\Omega$cm)$^{-1}$</th>
<th>Power Factor (m)</th>
<th>Activation energy (eV)</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>At 300K</td>
<td>At 525K</td>
<td>HT</td>
</tr>
<tr>
<td>1</td>
<td>0.0</td>
<td>1.1</td>
<td>1.3X10$^{-2}$</td>
<td>2.1X10$^{-2}$</td>
<td>0.501</td>
</tr>
<tr>
<td>2</td>
<td>0.01</td>
<td>0.92</td>
<td>1.5X10$^{-2}$</td>
<td>2.3X10$^{-2}$</td>
<td>0.482</td>
</tr>
<tr>
<td>3</td>
<td>0.05</td>
<td>0.82</td>
<td>1.56X10$^{-2}$</td>
<td>2.39X10$^{-2}$</td>
<td>0.512</td>
</tr>
<tr>
<td>4</td>
<td>0.1</td>
<td>0.73</td>
<td>1.7X10$^{-2}$</td>
<td>2.5X10$^{-2}$</td>
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</tr>
<tr>
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<td>0.90</td>
<td>1.8X10$^{-2}$</td>
<td>2.6X10$^{-2}$</td>
<td>0.496</td>
</tr>
<tr>
<td>6</td>
<td>1.0</td>
<td>1.0</td>
<td>1.9X10$^{-2}$</td>
<td>2.7X10$^{-2}$</td>
<td>0.507</td>
</tr>
</tbody>
</table>
Table 6.3: Compositional analysis of Lithium doped CuInSe$_2$ thin films

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Mole % of Li in CuInSe$_2$</th>
<th>Bath content in ppm</th>
<th>Film content in ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cu</td>
<td>In</td>
<td>Se</td>
</tr>
<tr>
<td>01</td>
<td>0.0</td>
<td>15.88</td>
<td>28.70</td>
</tr>
<tr>
<td>02</td>
<td>0.01</td>
<td>15.88</td>
<td>28.70</td>
</tr>
<tr>
<td>03</td>
<td>0.025</td>
<td>15.88</td>
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</tr>
<tr>
<td>04</td>
<td>0.050</td>
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<td>28.70</td>
</tr>
<tr>
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<td>15.88</td>
<td>28.70</td>
</tr>
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<td>0.1</td>
<td>15.88</td>
<td>28.70</td>
</tr>
<tr>
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<td>0.25</td>
<td>15.88</td>
<td>28.70</td>
</tr>
<tr>
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<td>15.88</td>
<td>28.70</td>
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<tr>
<td>09</td>
<td>0.75</td>
<td>15.88</td>
<td>28.70</td>
</tr>
<tr>
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Table 6.4: PEC cell performance parameters of Li-doped CuInSe$_2$ photoelectrode

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<th>Sr. No.</th>
<th>Mole % of Li in CuInSe$_2$</th>
<th>$V_{oc}$ (mV)</th>
<th>$I_{sc}$ (µA)</th>
<th>$\eta$ %</th>
<th>ff %</th>
<th>$\Phi_p$ (eV)</th>
<th>$V_{fb}$ (V)</th>
<th>$R_{sh}$ (Ω)</th>
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References
